Q-switched ruby laser alloying of Ohmic contacts on gallium arsenide epilayers[a)]

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Ohmic contacts of AuGe have been produced on GaAs epilayers by laser alloying. The contacts possess morphological and electrical properties which are superior to those formed by conventional alloying.

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The use of lasers for the formation of Ohmic contacts,[1] annealing,[2] recrystalization,[3] and enhanced vapor deposition[4] of semiconductors, metals, and other compounds has been reported recently. In this letter, we report on the use of a *Q-switched* ruby laser to form Ohmic contacts on GaAs *epilayers*. Earlier work of Pounds *et al.*[1] utilized long (~1 ms) ruby laser pulses to form similar contacts on *wafers*. The increased instantaneous power density of our *Q*-switched source relative to that of Ref. 1 (approximately two orders of magnitude greater) resulted in a lower specific contact resistance (by nearly an order of magnitude), while requiring less laser energy. The prominent feature of *Q*-switched laser alloying is that one can, essentially instantaneously, raise the interface temperature to a level much greater than that of the eutectic point. The rapid thermalization time of the epilayer during and following the deposition of laser energy relative to the time required for creation of nucleation sites inhibits the formation of surface irregularities, yielding improved contact electromorphological properties. In contrast, the conventional thermal alloying technique, which consists of melting a eutectic layer of, say, AuGe on a Sn-doped epilayer of GaAs,[5] results in "balling-up" and/or poor dimensional control of the contact metallization. The result of using a *Q*-switched ruby laser to produce Ohmic contacts is lower contact resistance and more uniform surface quality compared to that of conventional techniques or "long" pulse duration laser alloying.

The test samples used in this demonstration were formed by growing a 3-μ-thick conventional LPE epilayer of n-type [Sn doped (3×10^{16} cm^{-3})] GaAs on a semi-insulating (SI) GaAs substrate. The surfaces were then mildly etched in a solution of $H_2SO_4 : H_2O_2 : H_2O$ (4 : 1 : 1) for approximately 30 s. A 3000-Å-thick layer of gold-germanium (12% Ge) was then evaporated on this epilayer. During evaporation, the substrate temperature was estimated to be 150 °C. Three different sets of planar resistor arrays were formed using standard photolithographic techniques. Mesa etching to the SI substrate and gold etching to the epilayer thus determined the width and length, respectively, of the various resistor elements.

Ohmic contacts on a given sample were formed using two techniques. First, arbitrary areas of the sample were irradiated by a passively *Q*-switched single longitudinal mode ruby laser. The laser operated essentially in the TEM_{00} mode with an output energy of ~18 mJ in 15 ns. The Gaussian intensity spot size was determined to be ~1.5 mm in diameter, which corresponds to an energy density of ~1.02 J/cm^2 incident upon the GaAs chip. The AuGe-GaAs interface temperature was estimated by performing calorimetric measurements that determined the total laser energy absorbed by the sample during the alloying pulse. These measurements resulted in an interface temperature corresponding to approximately four times that of the AuGe eutectic point. That this result was reasonable was confirmed by microscope inspection of the alloyed samples, which revealed that melting of both the AuGe and GaAs regions had taken place. After measuring the resistance of these laser alloyed contacts, the entire sample was thermally alloyed at a temperature of 430 °C for approximately 3 min. Photographs of typical contacts formed by the two techniques are shown in Fig. 1. It is evident that the use of laser alloying forms more uniform Ohmic contacts [Fig. 1(a)] than that using a bulk-heating approach where the contacts are pitted irregularly [Fig. 1(b)]. For comparison, Fig. 1(c) shows a typical sample prior to alloying.

The specific contact resistance of the above formed contacts was calculated using the TLM method[6] and was found to be $\leq 7.04 \pm 5.14\times10^{-5}$ Ω cm^2 (which corresponds to $R_c \sim 4.9$ Ω for 200 μ of contact width) for the laser-alloyed contacts; while the thermally alloyed contacts yielded[7] $\leq 5.37 \pm 2.82\times10^{-4}$ Ω cm^2. That the contacts were Ohmic in nature was established by measuring the linearity of the I-V characteristic. The rather large (absolute) fluctuations in the resistance measurement of the thermally alloyed samples is indicative of the spatial contact inhomogeneities associated with this process. In contrast, the superior quality of the laser-alloying process with respect to contact resistance is evident.

In conclusion, we have demonstrated that laser alloying of Ohmic contacts on GaAs epilayers is a viable processing technique. The extension of this process to other laser sources, materials, and alloying techniques easily follows from these initial results. The uniformity of the laser exposed area, as well as improved electromorphological properties, makes this approach a reasonable alternative to existing technologies. Also, the localizability of the alloyed area and the advantage

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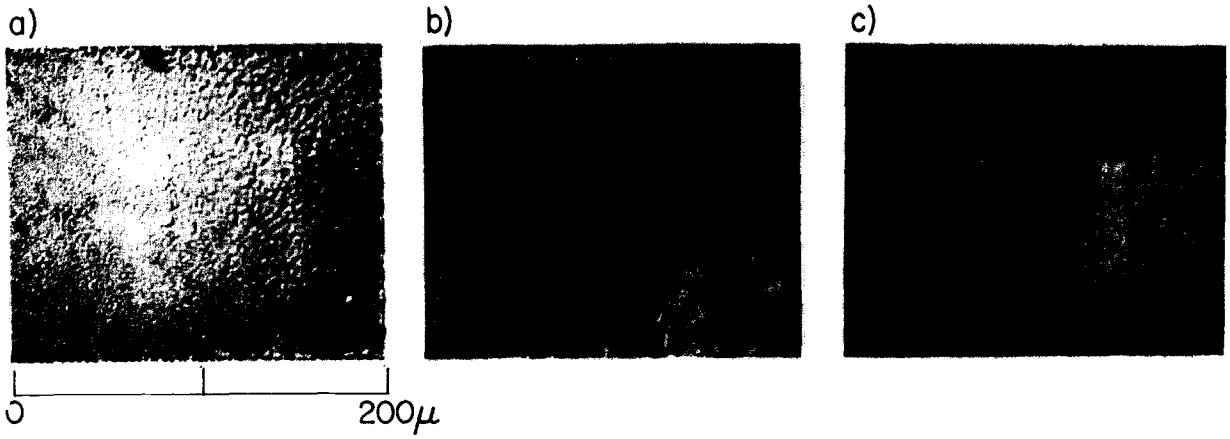

FIG. 1. Photographs of alloyed Au-Ge Ohmic contacts, and reference sample. (a) Ruby laser alloyed contact; (b) conventional bulk-heated thermally alloyed contact; (c) typical sample, prior to alloying.

of not requiring bulk heating adds a new technique to the growing area of laser chemistry.

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Elimination of stacking-fault formation in silicon by preoxidation annealing in $N_2/HCl/O_2$ mixtures

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The formation of oxidation-induced stacking faults in the surface regions of silicon wafers can be eliminated by a short-period anneal in a dry nitrogen atmosphere containing small concentrations of HCl and oxygen in the same furnace where subsequent oxidation will be carried out. This preoxidation anneal results in the prevention of fault nucleation without causing any problem like a nitridation reaction, an etch-pit formation, and a blotchy appearance on the silicon surface.

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The generation of oxidation-induced stacking faults (OSF's) in silicon wafers during high-temperature device processing[1] is an area of major concern in semiconductor manufacturing. These crystallographic defects are well known to have deleterious effects on the performance of many microelectronic devices, particularly charge-coupled imaging devices. As a result of numerous investigations aimed at the elimination of OSF nucleation sites or suppression of OSF growth, a variety of gettering techniques[2] have been developed with varying degrees of success.

More recently, Murarka *et al.*[3] have proposed a technique of eliminating the OSF formation which involves heating silicon wafers in an argon (or argon/HCl) ambient in the same furnace where subsequent oxidation will be carried out. They have shown that helium, hydrogen, krypton, neon, xenon, or their mixtures can be used as an inert ambient in place of argon gas. They, however, did not recommend the use of nitrogen gas, which is far less expensive and more easily obtainable in silicon device processing lines, due to an interaction with silicon.[4,5]

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